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MINIREVIEWS

Venous excess ultrasound: A mini-review and practical guide for its application in critically ill patients

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Abstract

Advancements in healthcare technology have improved mortality rates and extended lifespans, resulting in a population with multiple comorbidities that complicate patient care. Traditional assessments often fall short, underscoring the need for integrated care strategies. Among these, fluid management is particularly challenging due to the difficulty in directly assessing volume status especially in critically ill patients who frequently have peripheral oedema. Effective fluid management is essential for optimal tissue oxygen delivery, which is crucial for cellular metabolism. Oxygen transport is dependent on arterial oxygen levels, haemoglobin concentration, and cardiac output, with the latter influenced by preload, afterload, and cardiac contractility. A delicate balance of these factors ensures that the cardiovascular system can respond adequately to varying physiological demands, thereby safeguarding tissue oxygenation and overall organ function during states of stress or illness. The Venous Excess Ultrasound (VExUS) Grading System is instrumental in evaluating fluid intolerance, providing detailed insights into venous congestion and fluid status. It was originally developed to assess the risk of acute kidney injury in postoperative cardiac patients, but its versatility has enabled broader applications in nephrology and critical care settings. This mini review explores VExUS's application and its impact on fluid management and patient outcomes in critically ill patients.

Key Words: Diuretic; Point-of-care ultrasound; Ultrasound; Venous congestion; Venous excess ultrasound

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Core Tip: Precise fluid management in critically ill patients is a considerable challenge, as peripheral oedema is common and often complicates accurate assessment of their volume status. The Venous Excess Ultrasound (VExUS) Grading System has emerged as a valuable tool for assessing fluid intolerance and venous congestion across various clinical settings. This mini review emphasizes the application of VExUS to enhance fluid management strategies and its potential to improve patient outcomes. By integrating VExUS into clinical workflows, healthcare providers can better address fluid-related complications and optimize care for patients with complex needs.

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INTRODUCTION

Fluid administration, a fundamental aspect of critical care, is a simple yet sophisticated intervention that hinges on clinical judgement. To execute it correctly, clinical acumen is required, which, when done well, is often the defining characteristic of a remarkable clinician[1]. Underhydration and overhydration are common in clinical practice, and most importantly, both contribute to higher mortality rates[2,3]. With an ageing population in many countries globally, today's patient pool tends to present with multiple co-morbidities[4,5]. This adds to the complexity of clinical cases, posing additional challenges in achieving the delicate balance of fluid management. Technology advancements help overcome these challenges by integrating advanced diagnostic gadgets into the clinician's traditional clinical skills. One such tool is point-of-care ultrasound (POCUS). POCUS enhances the clinician's real-time assessment capabilities by providing valuable insights for diagnostic, monitoring, and therapeutic options[6]. Furthermore, it is simple to perform and readily available at the bedside.

In 2020, Beaubien-Souligny *et al*[7] conducted a study on grading system prototypes, namely Venous Excess Ultrasound (VExUS) A, VExUS B, VExUS C, VExUS D, and VExUS E, to predict the likelihood of acute kidney injury (AKI) in post-operative cardiac surgery patients. The study found that the VExUS C prototype had a high specificity of 96% in identifying severe venous congestion that may lead to AKI. The prototype involves measuring the size of the inferior vena cava (IVC) and analyzing the pulse-wave Doppler ultrasound on the hepatic vein, portal vein, and renal vein. The study concluded that post-operative cardiac surgery patients admitted to the intensive care unit (ICU) with at least two severe alterations in venous flow and an IVC diameter of 2 cm or more are at risk of AKI. Clinical medicine has since adopted the VExUS grading system. Subsequently, the clinical utility of VExUS extended to areas such as cardiology, nephrology, emergency medicine, and intensive care medicine.

This minireview provides a step-by-step practical guide for using the VExUS grading system in clinical practice. Before looking into the VExUS clinical usage, we will begin by elucidating the fundamental principles of ultrasonography, which will aid readers in comprehending the technical and interpretive aspects of the VExUS clinical application.

TECHNICAL ASPECTS OF VEXUS

In ultrasonic probes, the piezoelectric crystals are responsible for the generation of sound waves that form ultrasonic images. Typically, diagnostic ultrasonography uses 1–30 MHz sound waves[8]. We recommend low-frequency probes, particularly those within the frequency range of 1 to 5 MHz, for VExUS evaluation. This is because most of the structures being assessed, such as the hepatic vein, portal vein, and renal vein, are located deep within the abdomen. Among the low-frequency probes, there are two options: The curvilinear probe and the phased array probe. The curvilinear probe has a frequency range of 2 to 5 MHz, while the phased array probe has a frequency range of 1 to 5 MHz. We prefer the curvilinear probe as it has bigger footprint, allowing better lateral resolution compared to phased array probes[8]. Furthermore, when performing VExUS evaluation with a phased array probe, it may be necessary to adjust the color Doppler scale to a low flow velocity of 20–30 cm/s or switch to an abdominal preset[9].

In the VExUS grading system, pulsed wave (PW) Doppler analysis is one of the most important elements throughout the assessment. The Doppler study analyses the Doppler shift, which is the change in frequency of the reflected echo, to determine the relative motion, thus revealing the velocity and flow direction[10-12]. There are three Doppler modalities: Color Doppler, power Doppler, and spectral Doppler[13]. In the color Doppler mode, red typically denotes flow towards the transducer, and blue denotes flow away from the transducer. However, this remains true if only the color Doppler bars are not inverted, in which the red bar is positioned above the baseline and the blue bar is positioned beneath the baseline. Power Doppler will not denote the flow direction, but it is more sensitive when detecting low-velocity flow[14]. Therefore, in situations where color Doppler fails to capture any waves in low flow velocity vessels, switching to power Doppler could be beneficial. The types of spectral Doppler are continuous-wave and PW. PW Doppler mode evaluates the speed of blood flow at the sampling volume or PW gate area and shows blood flow velocity over time as a graph[12,15]. A positive deflection (above the baseline) on the trace indicates blood moving towards the transducer, while a negative deflection (below the baseline) indicates blood moving away from the transducer. In general, it is not advisable to use PW for flow velocities above 200 cm/s. This is because duplex ultrasound imaging, which combines brightness (B) mode and PW Doppler, cannot accurately measure velocities beyond this threshold (Nyquist limit) due to aliasing. Aliasing may lead to an underestimation of the velocity, as the Doppler signal falsely creates an appearance of the flow reversing or oscillating in the opposite direction[8,12,16]. In addition to the aliasing concern, the insonation angle has a significant impact on PW Doppler. Generally, an insonation angle between zero and 60 degrees should be maintained to avoid underestimating velocities[8,12]. Figure 1 provides an example of how the insonation angle affects the flow velocity measurement of the portal vein. In this example, there is underestimation of the actual velocity of the portal vein blood flow from about 30 cm/s to roughly 20 cm/s when the insonation angle is near 90 degrees.

Fortunately, VExUS focusses on identifying waveform pattern recognition rather than measuring precise velocities, which eliminates the complexities of Doppler shift formula calculation. Since precise velocities are not being measured, insonation angles are also of little concern. Moreover, the flow velocity for the hepatic vein is usually less than 40 cm/s [17], the portal vein is 20–40 cm/s[18], and the renal vein is less than 40 cm/s[19]. As a result, concerns about aliasing are not significant. These advantages make VExUS assessments easier to perform and user-friendly for even novice POCUS users. Table 1 summarizes key ultrasonography formulae relevant to the technical performance of VExUS. While these formulae underpin VExUS, they do not need to be calculated by clinicians in routine practice.

ACQUIRING IMAGES FOR VEXUS

In performing VExUS grading, the initial step involves identifying the IVC, which can be located using either a curvilinear or phased array probe. Figure 2 depicts the instructions for locating the IVC using a curvilinear probe, while Figure 3 illustrates the instructions for locating the IVC using a phased array probe. By locating the inferior cavoatrial junction and observing the hepatic vein's drainage into it, one can confirm the identification of the IVC and distinguish it from other vessels based on these anatomical landmarks. In contrast to the IVC, the aorta tends to be pulsatile, with a thicker and brighter hyperechoic wall. The optimal location for the IVC's size measurement is 3-5 cm away from the inferior cavoatrial junction or 2 cm away from the junction where the hepatic vein drains[20-23]. Figure 4 displays the IVC images obtained *via* the subcostal approach. To guarantee the precision of the IVC measurement, it is recommended to do the antero-posterior internal diameter measurement for both the longitudinal and transverse axis. At times, body habitus can make it difficult to obtain clear images *via* subcostal view, and clinicians may need to identify the IVC using a right-lateral intercostal approach, also known as transhepatic view. However, it is important to recognise that the IVC measurements obtained from the subcostal view and right lateral approach may not be directly comparable due to limited studies supporting their interchangeability. The right lateral approach often serves as a valuable rescue view for challenging body habitus, but the results obtained need to be interpreted cautiously. Integrating artificial intelligence guidance software into current ultrasound technology could potentially address this issue and improve the accuracy of IVC evaluation[24-28]. According to the VExUS grading system, an IVC < 2 cm indicates grade zero with no venous congestion; if the IVC is greater than or equal to 2 cm, proceed with the Doppler study analysis of the hepatic, portal, and renal veins.

As shown in Figure 5, you can identify the hepatic vein using either the subcostal approach or the right lateral intercostal approach, with the pointer directed towards the patient's cephalad and right. Hepatic veins consist of right, middle, and left hepatic veins; any one of them can be analyzed for VExUS. The portal vein can be identified *via* the subcostal approach, lateral intercostal approach, or intercostal approach at the mid-clavicular line, as depicted in Figure 6. It is easily identifiable due to its hyperechoic vessel wall and typically exhibits hepatopetal flow (blood flow that is directed toward the liver) in a normal situation, as indicated by the red color when using a color Doppler.

Lastly, the most technically challenging vessels are renal veins. Acquiring images of the renal interlobar or arcuate veins can be challenging due to their deep location within the abdomen. Once the color Doppler is activated and the renal vein is not visible, you can improve detection by reducing the pulse repetition frequency. If visibility remains insufficient, increasing the color gain may enhance the signal but be cautious of excessive noise due to the high gain setting. If these adjustments still fail to produce a satisfactory image, consider scanning the left renal veins. The failure rate for detecting a renal vein, especially in challenging candidates with obese body habitus, can be as high as 25%[29].

In the hepatic vein Doppler study, concomitant electrocardiogram (ECG) recordings are recommended. Nevertheless, this is not universally practised, since many regions with limited resources might lack the necessary ECG tracer technology in most of their portable POCUS devices. Methodologically, it is still possible to accurately perform the hepatic vein Doppler study, although the analysis of the waveform may become somewhat less accurate in the absence of the guidance of an ECG trace. Figure 7 depicts the hepatic Doppler waveform pattern in a normal condition. There are typically three distinct phases, each of which corresponds to the cardiac cycle[30]. The right atrial contraction causes a minor elevation in pressure and minimal backflow into the hepatic vein, resulting in the small amplitude of the atrial contraction waveform, known as the 'a' wave. As the retrograde flow flows from the right atrium towards the hepatic vein, the 'a' wave appears above the baseline. During ventricle systole, tricuspid annulus elongation produces suction power, facilitating the venous return to the right atrium. This creates the largest anterograde flow from the hepatic vein into the right atrium, resulting in the appearance of an S wave below the baseline. Finally, during the ventricle diastole, blood flows from the right atrium into the right ventricle, giving rise to another anterograde flow of hepatic vein into the right atrium, known as the D wave. This wave is typically smaller in amplitude than the S wave. Between the S wave and the D wave transition, there is a V wave, which corresponds to atrial overfilling just prior to tricuspid valve opening[31]. In the cases of venous congestion or elevated right atrial pressure, the amplitudes of the 'a' and V waves will become more prominent, while the amplitudes of the S wave will decrease. In extreme cases, reversed flow may even occur. The

Table 1 The essential ultrasonography formulae relevant to venous excess ultrasound

Formula	Relevance
$\lambda = c/f$. λ is the wavelength, c stands for the sound velocity in the tissue, and f is the frequency[8,11,12]	The equation illustrates the inverse relationship between frequency and wavelength. The lower frequency corresponds to longer wavelengths, which allow them to penetrate deeper into the tissues as longer wavelengths reduce scattering and absorption. However, longer wavelengths lead to reduced spatial resolution, thereby diminishing the ability to distinguish between two objects. Thus, lower-frequency probes have better penetration but lower resolution images, while higher-frequency probes have the opposite characteristics
Doppler shift = $(2 \times f) \times (V/c) \times \cos\theta$. f is ultrasound frequency, V stands for blood flow velocity, c for speed of sound in the tissue, and θ for insonation angle	The Doppler shift is directly proportional to blood flow velocity, and aliasing tends to happen when the Doppler shift surpasses the Nyquist limit[12,13]. Besides, this formula illustrates the importance of the insonation angle in the PW study. Adjusting PW's insonation angle to zero, or at least less than 60 degrees, is ideal as it maximizes the Doppler shift at zero degrees ($\cos 0 = 1$), whereas at 90 degrees ($\cos 90 = 0$), there is essentially no Doppler shift
Nyquist limit = PRF/2. PRF stands for pulse repetition frequency	PRF is the rate at which the ultrasound system emits pulses of sound waves and receives their echoes. It is also known as the sampling rate, measured in hertz (Hz), and typically ranges from 1000 to 5000 Hz in clinical settings
PRF = 1/pulse duration. PRF stands for pulse repetition frequency. Pulse duration is the period between pulses	According to the inverse proportional relationship, the lower the PRF, the longer the pulse duration. Prolonging the pulse duration allowed for deeper transmission and improved sensitivity to low-velocity flow. But the trade-off features of lower PRF will include lowering the Nyquist limit and increasing the chances of aliasing, where the Doppler signal falsely creates an appearance of the flow reversing or oscillating in the opposite direction[12,13]

PRF: Pulse repetition frequency.

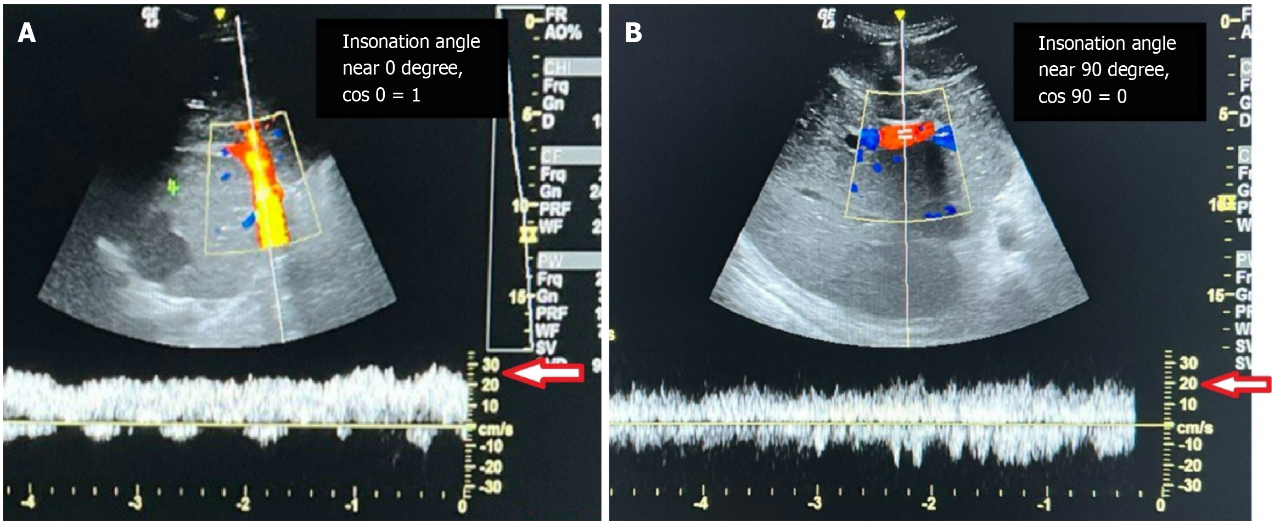

A
Insonation angle near 0 degree, cos 0 = 1
B
Insonation angle near 90 degree, cos 90 = 0
30
20
10
cm/s
-10
-20
-30
-4
-3
-2
-1
0

Figure 1 The influence of the insonation angle of the pulse wave spectral Doppler on the flow velocity measurement of the portal vein. A: The left-hand side image showed an insonation angle of near 0 degrees; B: The right-hand side image showed an insonation angle of near 90 degrees for the portal vein of the same patient in the same setting. We underestimated the actual velocity of the portal vein blood flow from about 30 cm/s to roughly 20 cm/s when the insonation angle is near 90 degrees.

interpretation of the hepatic vein Doppler waveform entails comparing the relative amplitudes of the systolic (S) and diastolic (D) waves; therefore, identifying the phases of the cardiac cycle is relatively important for the waveform interpretation. Thus, it is always advisable to connect the 3-lead ECG module to the dedicated port of the ultrasound machine to have a simultaneous ECG trace alongside the Doppler waveform. On the ECG, the P wave corresponds to atrial depolarization, the QRS complex corresponds to ventricular depolarization, and the T wave corresponds to ventricular repolarization. Therefore, when concurrent ECG tracing is present, we can identify the systole phase from the peak of the R wave to the midpoint of the T wave, and the diastole phase from the midpoint of the T wave to the peak of the R wave.

The portal vein, formed by the confluence of the splenic and superior mesenteric veins, accounts for 75% of the blood flow to the liver. It serves as the primary vessel of the portal venous system, located posterior to the hepatic artery and common bile duct and extending towards the hepatic hilum, where it bifurcates into the right and left branches[33]. In the context of VExUS, it is advisable to assess the main portal vein rather than using the other branches, as there may be cases of discordant waveforms[34]. Given the considerable distance between the portal vein and the right atrium, in normal conditions the blood flow in the portal vein typically exhibits a monophasic, low velocity Doppler signal with slight respiratory variation, mostly at a velocity ranging from 20 to 40 cm/s[18,35]. The pulatility fraction, or pulsatility index, is evaluated by the formula of [(maximal velocity minus minimum velocity)/maximal velocity][36,37]. A pulsatility fraction

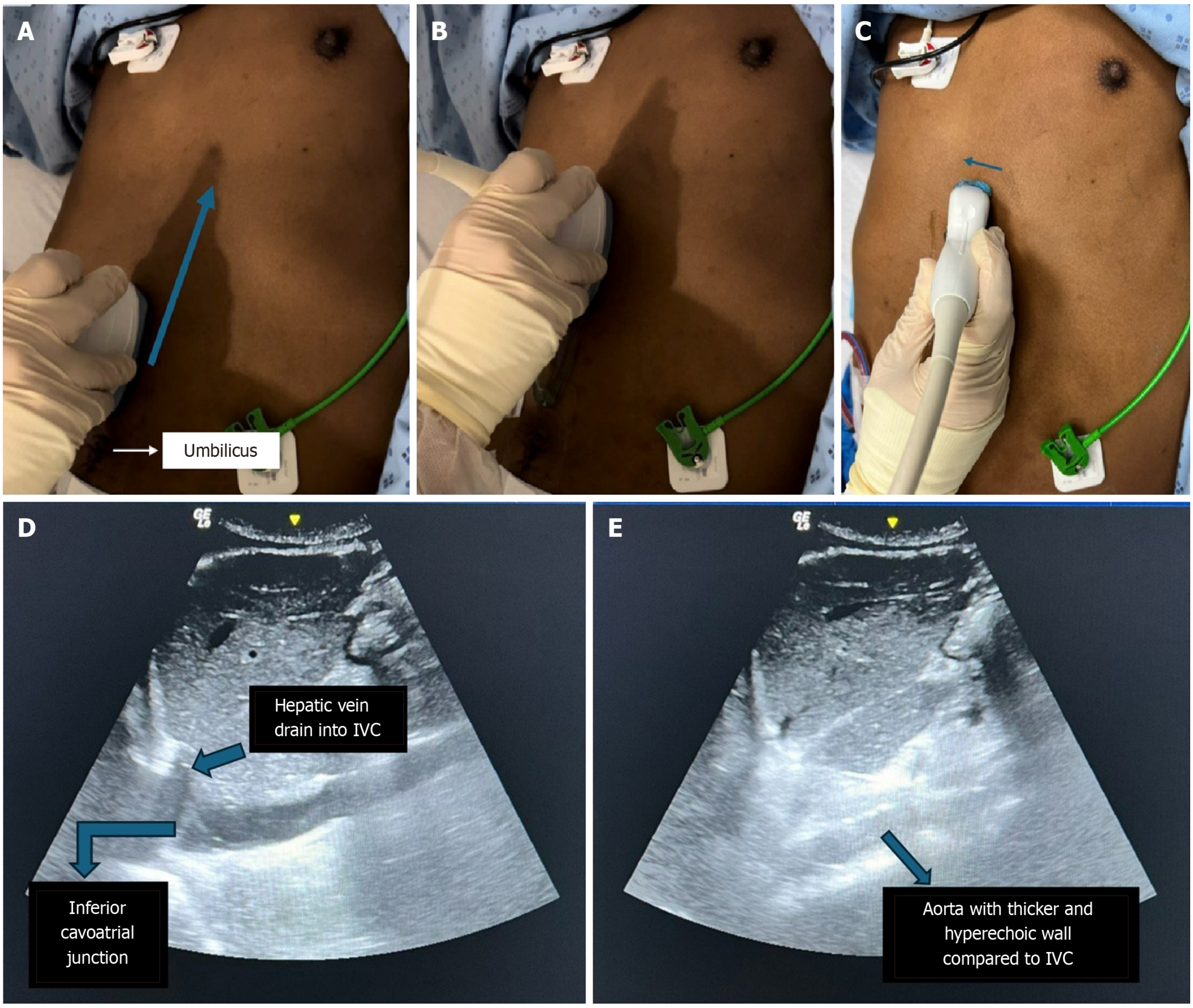

A
Umbilicus
B
C
D
Hepatic vein drain into IVC
Inferior cavoatrial junction
E
Aorta with thicker and hyperechoic wall compared to IVC

Figure 2 Measures for locating the inferior vena cava using a curvilinear probe. A: Firstly, place the curvilinear probe near the umbilicus, then slide it cephalad, with the indicator pointing towards the patient's head; B: Once probe reaching subxiphoid area, you should be able to visualize the liver; C: Tilt the probe slightly towards the patient's right, and the inferior vena cava (IVC) will be seen; D: Locate the anatomical landmarks of the inferior cavoatrial junction and the hepatic vein draining into the IVC to confirm the identification of the IVC; E: To check that the IVC is identified correctly, tilt the probe slightly to the patient's left, and an aorta with a thicker and more hyperechoic wall will be seen.

or pulsatility index of less than 30% is considered normal, 30%–50% is considered mildly abnormal, and more than 50% is considered severely abnormal. Figure 8 shows some examples of the portal vein Doppler waveform.

The renal vein is the most difficult vessel to image, but its proximity to the renal artery makes it easy to interpret its waveform pattern. The renal artery waveform provides a reference point for identifying systolic and diastolic cardiac cycles. Figure 9 shows some examples of the renal vein Doppler waveform. In normal circumstances, the renal vein should appear as a continuous monophasic Doppler flow throughout the cardiac cycle, but as it becomes more congested, it will appear to have biphasic flow with systole and diastole. In severe venous congestion, there might be a complete pause of renal vein flow during the systole phase. This is because the kidney is an encapsulated organ, and venous congestion with its back pressure effect can significantly impede systolic renal venous flow[38].

INTERPRETING VEXUS

In VExUS, there are 4 grades: Grade 0 indicates that the IVC measures less than 2 cm, signifying no congestion in any organ, while Grade 1, with an IVC of 2 cm or more and any combination of normal or mildly abnormal waveforms, reflects only mild congestion. Grade 2 is characterized by an IVC of 2 cm or more along with one severely abnormal waveform, indicating severe congestion in a single organ, whereas Grade 3 denotes severe congestion affecting at least two organ systems, represented by an IVC of 2 cm or more and two or more severely abnormal waveforms[7,32,34]. Figure 10 provides a graphic representation of the interpretation of the VExUS grading system. This grading system aids clinicians in identifying venous congestion, which can significantly impact organ function and cellular perfusion in patients.

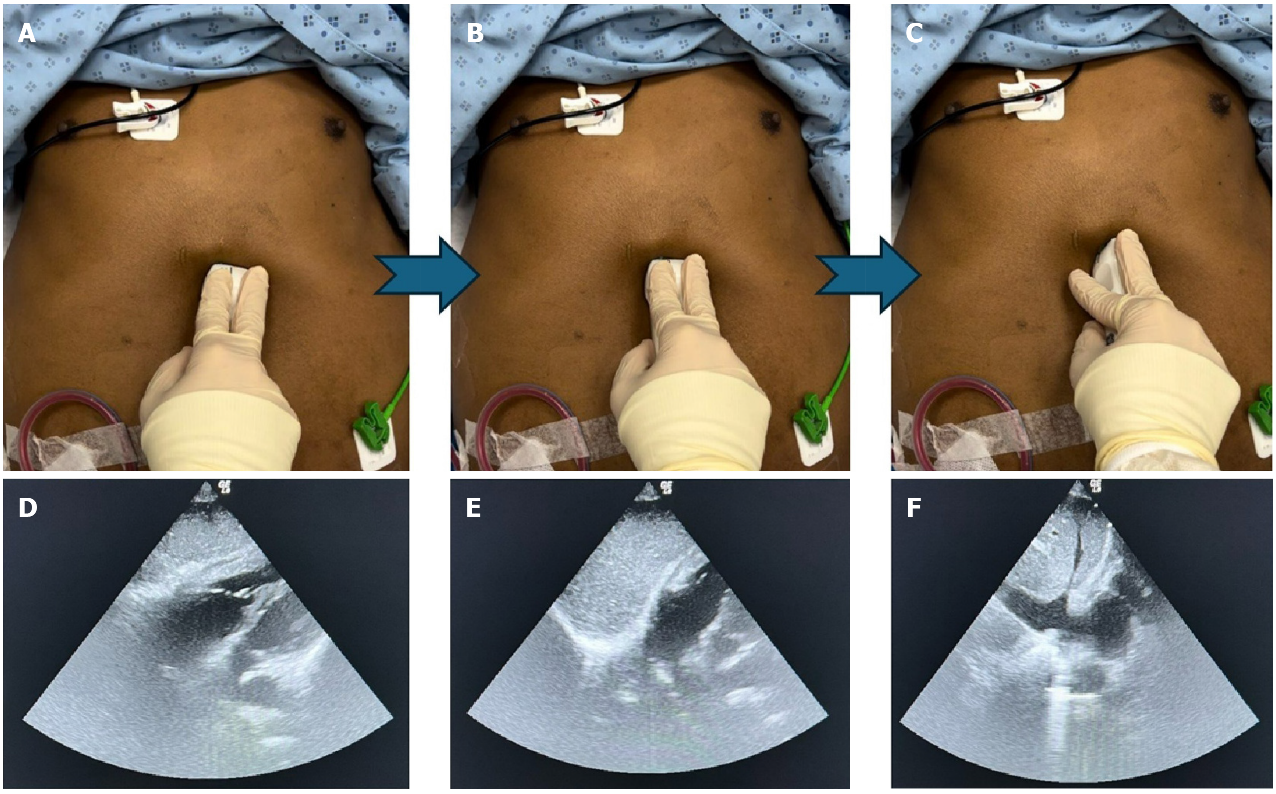
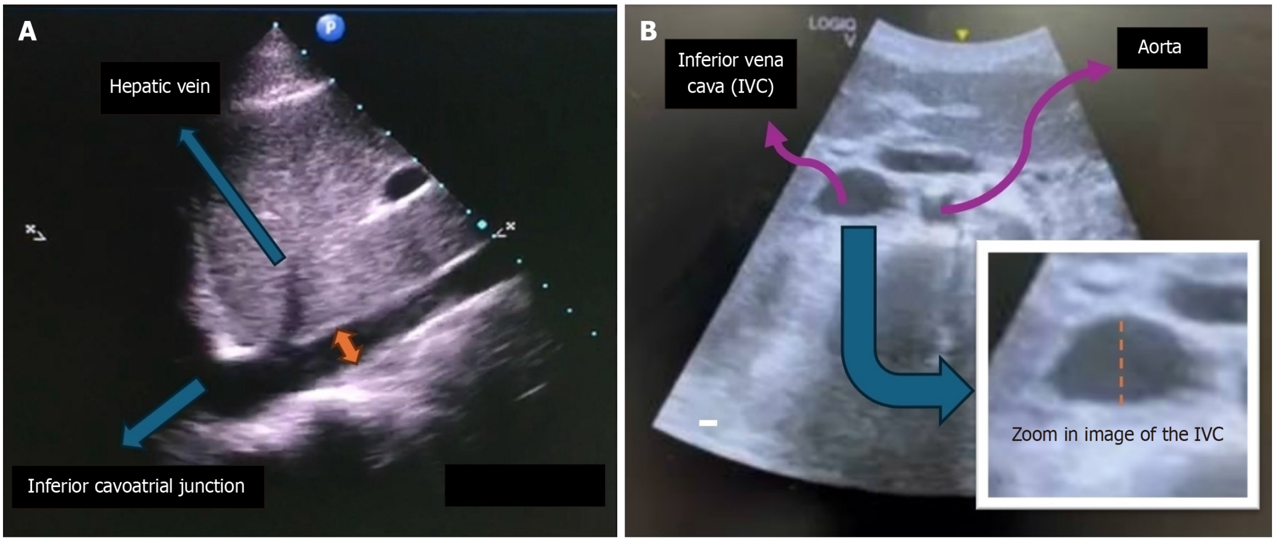


Figure 3 Measures for locating the inferior vena cava using a phased array probe. A and D: Firstly, get an ideal subcostal four chambers echo view; B and E: Rock the probe towards the patient's right, bringing the right atrium (RA) to the center of the screen; C and F: Once the RA is in the center, rotate the probe in an anticlockwise direction to open up the inferior vena cava.

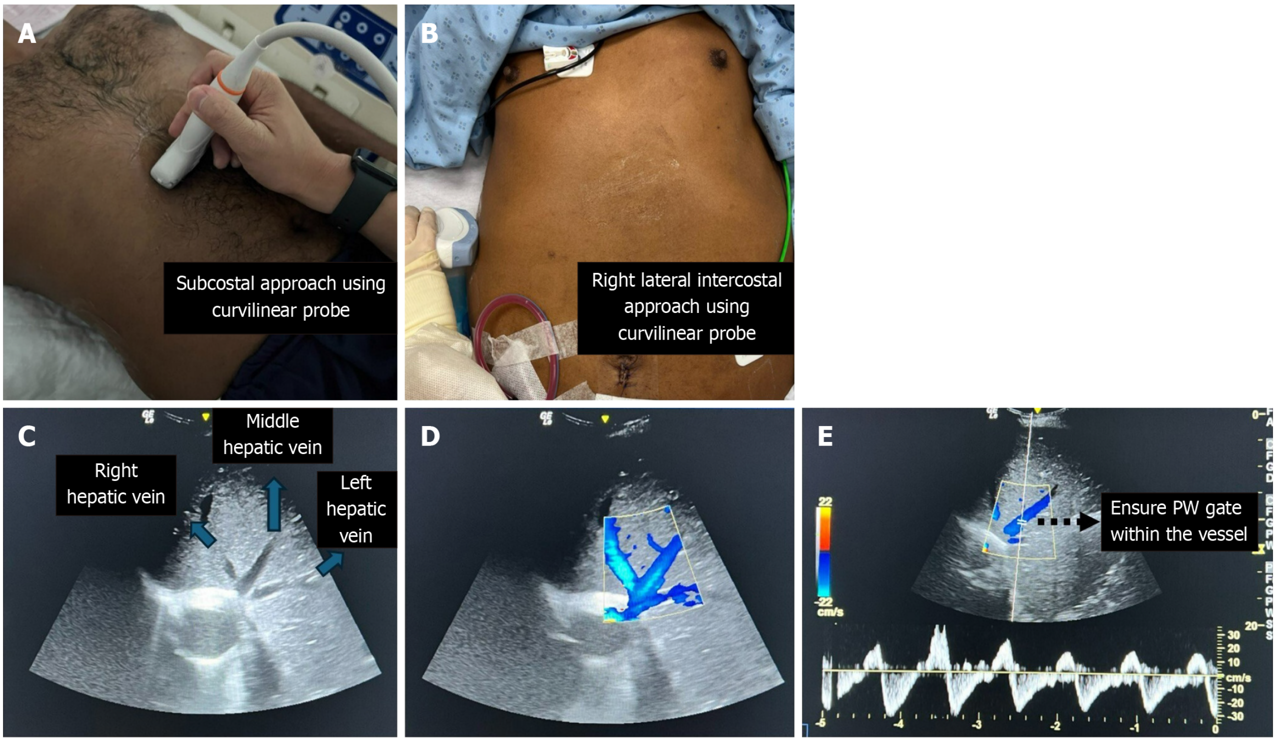

[redacted]

The optimal location to measure the IVC's internal diameter along its longitudinal axis is 3-5 cm from the inferior cavoatrial junction or 2 cm from where the hepatic veins meet, as the orange arrow shows

When measuring the IVC's internal diameter along its transverse axis *via* a subcostal approach, try to obtain the most rounded IVC to avoid foreshortening of the vessel and minimise error

Figure 4 Inferior vena cava images obtained *via* the subcostal approach. To guarantee the precision of the Inferior vena cava measurement, it was recommended to do the antero-posterior internal diameter measurement for both the longitudinal and transverse axis. A: Longitudinal axis; B: Transverse axis.

The delivery of oxygen is dependent on arterial oxygen levels, haemoglobin concentration, and cardiac output, with the latter influenced by preload, afterload, and cardiac contractility. A delicate balance of these factors ensures that the cardiovascular system can respond adequately to varying physiological demands, thereby safeguarding tissue oxygenation and overall organ function during states of stress or illness. In normal physiology, preload or venous return is dependent on mean systemic filling pressure (Pmsf) and right atrial pressure. The venous system contains stressed and


A
Subcostal approach using curvilinear probe
B
Right lateral intercostal approach using curvilinear probe
C
Right hepatic vein
Middle hepatic vein
Left hepatic vein
D
E
Ensure PW gate within the vessel
22
-22
cm/s
30
20
10
cm/s
-10
-20
-30

Hepatic vein without color doppler

Hepatic vein with color doppler

Pulse wave (PW) spectral doppler study of hepatic vein

Figure 5 Measures for locating the hepatic vein using a curvilinear probe and performing a pulse wave spectral Doppler study on the hepatic vein. Locating the hepatic vein using either the subcostal approach or the right lateral intercostal approach, with the pointer directed cephalad and towards the patient's right. A: Subcostal approach; B: Right lateral intercostal approach; C: Hepatic veins consist of right, middle, and left hepatic veins; any one of them can be analyzed for Venous Excess Ultrasound; D: Activating the color Doppler revealed the hepatic vein in blue; E: Once identified, place the pulse wave sample volume, also known as the PW gate, within the hepatic vein.

unstressed volumes, with the latter being blood that does not exert pressure against vessel walls[39]. The stressed volume, venous capacitance, and venous compliance all influence the Pmsf, which typically ranges from 7 to 10 mmHg when there is no flow in the systemic vascular system[40]. Clinical conditions can shift these volumes; for example, sepsis-induced vasodilatation increases venous compliance and unstressed volume, which reduces Pmsf[41]. Conversely, in a fluid overload situation, there is an increase in total blood volume and stressed volume, thus increasing the Pmsf. As a result, an increase in Pmsf can lower organ perfusion pressure, calculated as mean arterial pressure minus Pmsf, thereby restricting blood flow and affecting organ perfusion[42]. While fluid responsiveness warrants careful consideration, administering fluid boluses to individuals with fluid intolerance is not advisable[43-45].

One of the mainstays of fluid management in venous congestion is the use of loop diuretics, *e.g.*, frusemide. Ultrafiltration through hemodialysis, which includes intermittent hemodialysis and continuous kidney replacement therapy, is an effective alternative to diuretics for removing excess fluid from the body. The administration of diuretic and hemodialysis necessitates meticulous clinical discernment, as an incorrect dosage may result in serious consequences such as hypovolemic shock or inadequate fluid removal. However, traditional assessments often fall short, particularly when directly assessing fluid composition within the body, necessitating the use of integrated care techniques[46,47]. The VExUS grading system provides us with detailed information on fluid intolerance. A higher grade is indicative of fluid intolerance. Thus, the VExUS grading system serves as a "green light" sign for diuresis or fluid removal when the VExUS grade is 1-3 and a "red light" sign to halt diuresis or fluid removal when the VExUS grade is 0.

CLINICAL APPLICATIONS OF VEXUS

Due to its clinical importance, researchers conducted numerous studies to explore the clinical applications of VExUS, and Table 2 is the summary of studies relevant to VExUS. Additionally, Table 3 presents hypothetical clinical scenarios where the application of VExUS in clinical medicine is possible.

PREDICTION OF AKI

Both Beaubien-Souligny *et al*[7] and Viana-Rojas *et al*[48] studies demonstrated that systemic venous congestion measured by VExUS can predict the development of AKI. The difference lies in the fact that Beaubien-Souligny *et al*[7] focused on

Table 2 Summary of the studies relevant to utility of venous excess ultrasound in various clinical settings

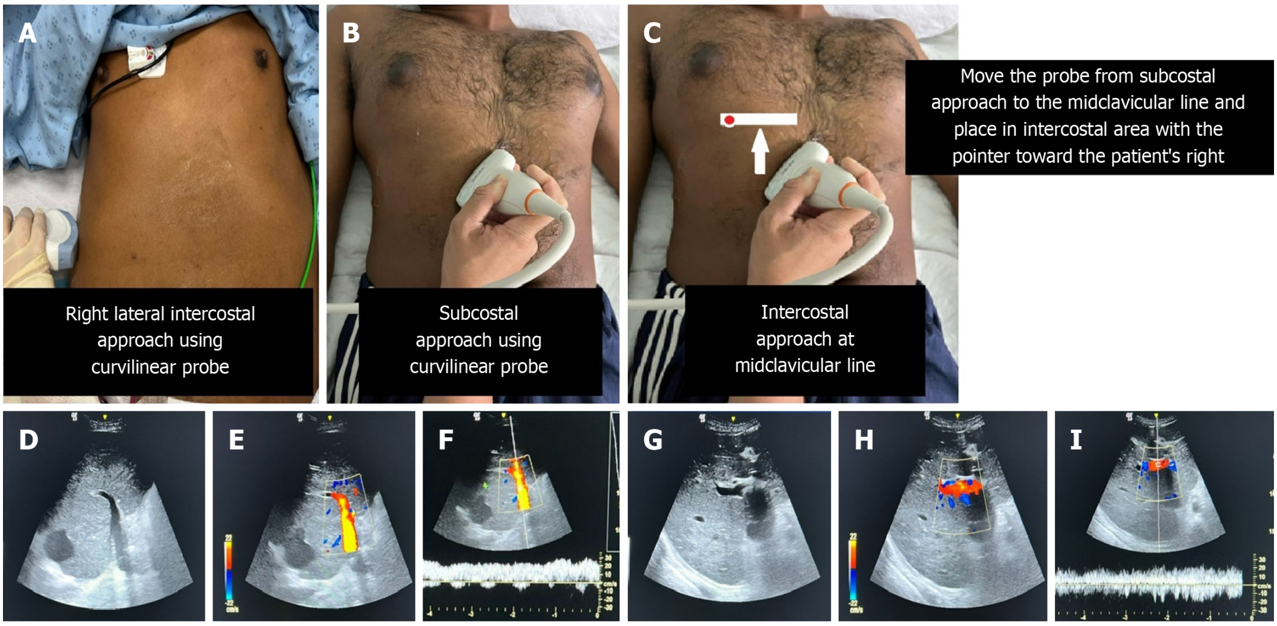
Ref.	Study objectives	Clinical outcomes
Andrei *et al*[53], 2023	Prospective observational study to describe prevalence of venous congestion based on VExUS grading in general ICU patients, and its association with AKI injury and 28-day mortality	Low prevalence of severe venous congestion (16% and 6% of VExUS grades 2 and 3 respectively), which did not change over the study period. No significant association between admission VExUS scores and AKI (P = 0.136) or 28-day mortality (P = 0.594)
Beaubien-Souligny *et al*[7], 2020	To develop a prototypical VExUS grading system and to validate the model in predicting post cardiac surgery related AKI	Severe congestion (Grade 3) defined by the VExUS C grading system was the most strongly associated with AKI (HR = 3.69, 95%CI: 1.65–8.24, P = 0.001)
Bhardwaj *et al*[52], 2020	Prospective cohort study on the correlation between serial VExUS score and AKI in patients with cardiorenal syndrome	Resolution of AKI showed significant correlation with improvement in VExUS grade (P = 0.003). There was significant association between changes in VExUS grade and fluid balance (P = 0.006)
Landi *et al* [54], 2024	Prospective, observational study to determine if venous congestion (using VExUS grading) predicts heart failure related hospitalization and mortality in patients admitted to the emergency department, with acute decompensated heart failure	In patients with a VExUS grade of 3, the probability of both readmission and mortality was significantly greater compared to those with lower grades
Longino *et al*[49], 2024	Prospective cohort study to assess the diagnostic accuracy of VExUS grade for elevated intracardiac pressure	AUC values for VExUS as predictor of right atrial pressure $>$ 10 mmHg was 0.9 (95%CI: 0.83-0.97), and significantly greater than inferior vena cava diameter or inferior vena cava collapsibility index
Rihl *et al* [51], 2023	To determine whether VExUS score can be used to guide decongestion in ICU patients with severe AKI, and whether the modification of the score is associated with an increase in the number of RRT-free days in 28 days	Patients with higher VExUS grades ($>$ 1) used more diuretics. Patients who reduced the VExUS grade in 48 hours had more RRT-free days at Day 28 (28.0; 8.0-28.0) than patients who did not reduce VExUS grade (15.0; 3.0-27.5), P = 0.012
Rola *et al* [32], 2021	Case series on the use of VExUS in identifying pathophysiology and guiding clinical management	Case 1 Continuous drainage of ascites was performed until 12 L was removed. Intravenous frusemide was restarted at a higher dose until a net balance of negative 1000 mL per 8-hour shift was achieved. Case 2 A planned surgical cholecystectomy was cancelled as ultrasound results showed venous congestion instead of cholecystitis. Patient was discharged home with frusemide and an outpatient cardiology review. Case 3 A patient with preexisting pulmonary hypertension received high-dose intravenous frusemide until a net balance of negative 1200 mL per 24 hour was achieved, followed by dose titration to achieve a negative balance of 3200 mL per 24 hours. Dobutamine was further decreased to 3 mcg/kg/min. Case 4 A patient with severe venous congestion and hyperkalemia was treated with intravenous frusemide 200 mg and thereafter hemodialysis was started as there was no diuretic response. A repeat VExUS scan showed improvement in venous congestion, and the patient produced 800 mL of urine. Further diuresis with intravenous frusemide infusion 200 mg/day and spironolactone 50 mg twice a day was given, and a negative fluid balance of 15.5 L was achieved. Case 5 Patient underwent ultrafiltration, and 5 L of fluid was removed within 24 hours. Over the next 48 hours, lactate normalized, and vasopressor requirements improved. VExUS showed refractory shock was related to volume overload and RV dysfunction
Viana-Rojas *et al* [48], 2023	Prospective, single-center study to evaluate the association between venous congestion assessed with VExUS and the incidence of AKI in patients with acute coronary syndrome	As the degree of VExUS increased, a higher proportion of patients developed AKI: VExUS = 0 (10.8%), VExUS = 1 (23.8%), VExUS = 2 (75.0%), and VExUS = 3 (100%; P < 0.001). A significant association between VExUS $\geq$ 1 and AKI was found (odds ratio: 6.75, 95%CI: 2.21–23.7, P = 0.001)
Wong *et al* [50], 2024	Single-center, observational study to evaluate the utility of VExUS to access volume status, in relation to patient’s weight and fluid removal during dialysis	Patients with normal VExUS grades and elevated VExUS grades had no difference in starting weight, dry weight, or fluid removal. Patients with VExUS grades $>$ 1 had more fluid removed than those with VExUS grade 0. All patients with VExUS grades $>$ 1 had impaired right ventricular systolic function

VExUS: Venous excess ultrasound; AKI: Acute kidney injury; ICU: Intensive care unit; HR: Hazard ratio.

Table 3 Hypothetical clinical scenarios where the application of venous excess ultrasound in clinical medicine is possible

Clinical scenario	Clinical application of VExUS
Cardiomyopathy cases such as ischemic cardiomyopathy, septic cardiomyopathy, dengue cardiomyopathy *etc.*	By detecting the presence of venous congestion *via* the VExUS grading system, it helps the clinician to decide when to cease fluid therapy. Conversely, when no venous congestion is detected using VExUS, clinicians may be guided to cease diuretic therapy
End stage renal failure	By detecting the presence of venous congestion *via* the VExUS grading system, it helps the clinician to optimize the adequacy of fluid removal *via* dialysis
Cases required large amount of fluid resuscitation such as diabetic ketoacidosis, hyperosmolar hyperglycemic state *etc.*	By detecting the presence of venous congestion *via* the VExUS grading system, it helps the clinician to detect the threshold to cease the fluid resuscitation
Acute pulmonary oedema secondary to cardiomyopathy, hypoalbuminemia, hypertensive emergency, acute renal failure, acute liver failure *etc.*	By detecting the absence of venous congestion *via* the VExUS grading system, it helps the clinician to detect the threshold to cease the diuretic therapy

VExUS: Venous excess ultrasound.


A
B
C
Move the probe from subcostal approach to the midclavicular line and place in intercostal area with the pointer toward the patient's right
Right lateral intercostal approach using curvilinear probe
Subcostal approach using curvilinear probe
Intercostal approach at midclavicular line
D
E
F
G
H
I

Portal vein without color doppler

Portal vein with color doppler

Pulse wave (PW) spectral doppler study of portal vein

Portal vein without color doppler

Portal vein with color doppler

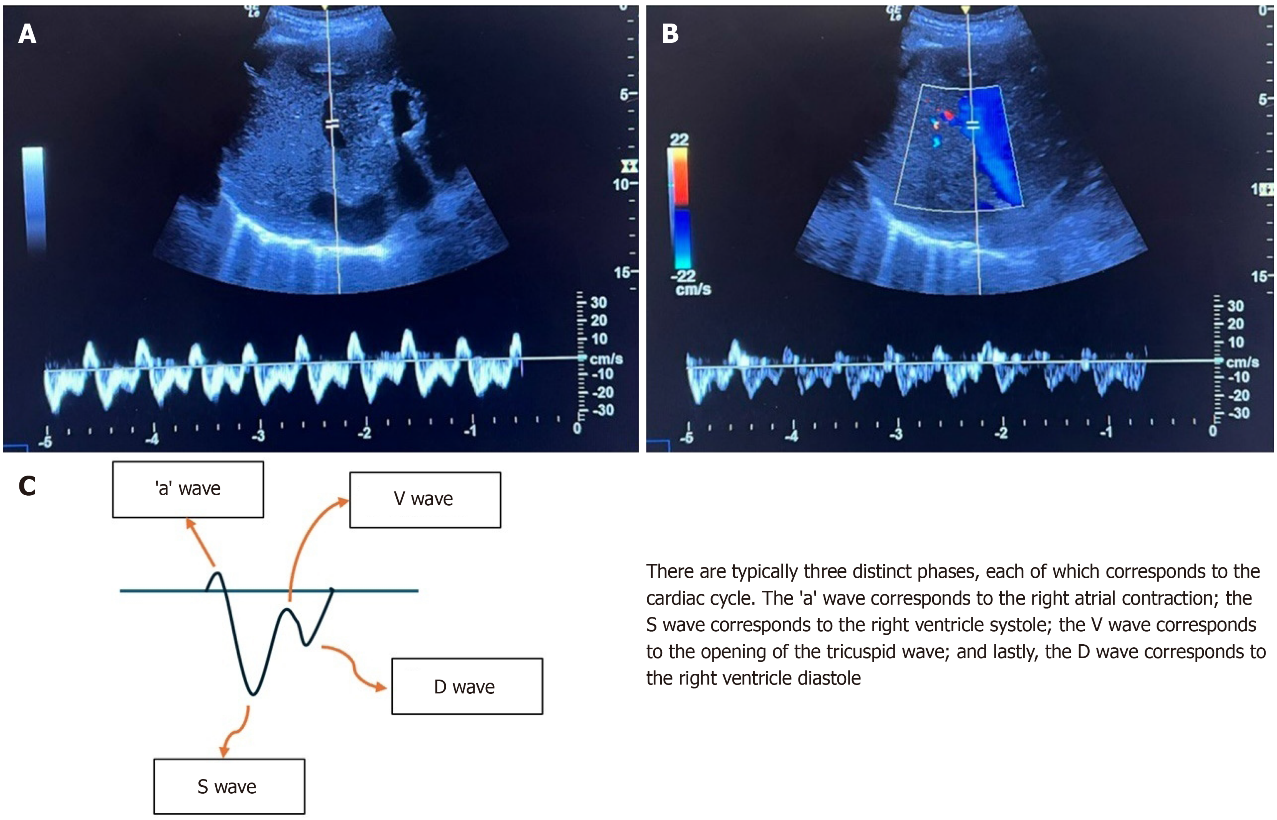
Pulse wave (PW) spectral doppler study of portal vein

Figure 6 Measures for locating the portal vein using a curvilinear probe and performing a pulse wave spectral Doppler study on the portal vein. On the left-hand side of the image, we locate the portal vein using the right lateral intercostal or subcostal approach. A: Right lateral intercostal approach; B: Subcostal approach. On the right-hand side of the image, we locate the portal vein using the intercostal approach at the midclavicular line; C: Intercostal approach at the midclavicular line. The portal vein images on each side exhibit slight differences, as do the insonation angles of the portal vein and the pulse wave gate; D-F: Right lateral intercostal or subcostal approach will give an insonation angle of near 0 degree; G-I: Intercostal approaches at the midclavicular line will give an insonation angle of near 90 degrees, which could underestimate the flow velocity measurement.

the post-cardiac surgery population, while Viana-Rojas *et al*[48] studied patients with acute coronary syndrome. The other study by Longino *et al*[49] found that VExUS grade was strongly linked to right atrial pressure, mean pulmonary arterial pressure, pulmonary capillary wedge pressure, and AKI in hospitalized patients.

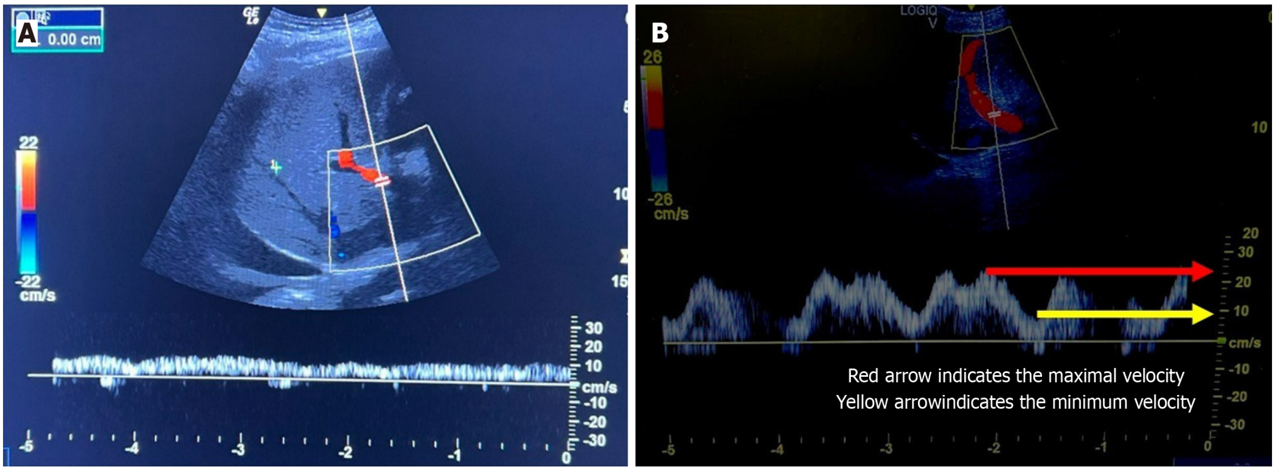
GUIDING FLUID REMOVAL

The ACUVEX study[50], a single-center observational study with 33 study samples, found that fluid removal improves venous congestion among those with elevated VExUS scores. Despite the improvements, it's noteworthy that neither the left ventricle's systolic function parameter (left ventricular outflow tract velocity time integral) nor the right ventricle's systolic function parameter (tricuspid annular plane systolic excursion) showed any improvement. This implies that the improvement in the VExUS score could precede the systolic parameters of the right and left ventricles, or that the improvements in the score may not have a direct correlation with the ventricles' cardiac performance. Besides, this study



There are typically three distinct phases, each of which corresponds to the cardiac cycle. The 'a' wave corresponds to the right atrial contraction; the S wave corresponds to the right ventricle systole; the V wave corresponds to the opening of the tricuspid wave; and lastly, the D wave corresponds to the right ventricle diastole

Figure 7 The morphology of the hepatic vein pulse-wave Doppler waveform in a normal condition. A: Hepatic vein without color doppler; B: Hepatic with color doppler; C: Hepatic vein pulse-wave doppler waveform in a normal condition.

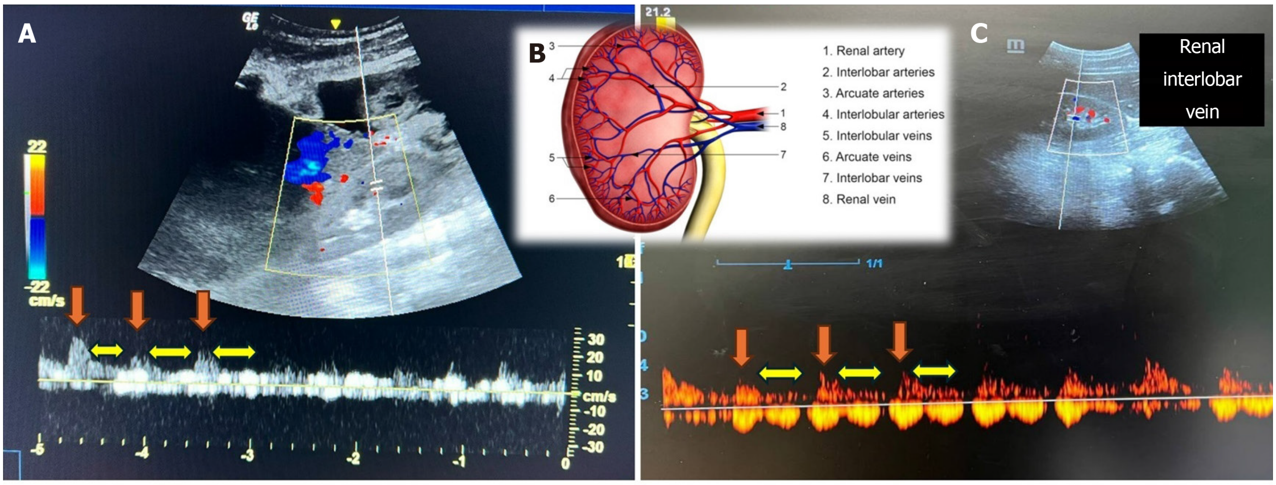


Red arrow indicates the maximal velocity
Yellow arrowindicates the minimum velocity

Figure 8 Examples of the portal vein Doppler waveform. A: In normal condition, the portal vein Doppler waveform exhibit a monophasic flow; B: In a congested portal vein, the portal vein doppler waveform exhibit a pulsatility index > 50%.

reveals individuals with elevated VExUS scores also exhibited both right and left ventricle dysfunction. This observation prompted the authors to hypothesize that the VExUS score could potentially indicate cardiac function, not just volume status. However, given the limited sample size, further research is necessary to explore all these hypotheses. As well as the ACUVEX study, Rola *et al*[32] shared a case series of a patient with pulmonary hypertension and another obstetric case where VExUS-guided hemodialysis fluid removal led to a better clinical outcome.

In addition, the AKIVEX study[51] showed patients with a reduced VExUS score within 48 hours had more kidney replacement therapy-free days at day 28 compared to those without a reduced score. AKIVEX[51], a quasi-experimental study, involved a larger sample size analysis of 90 patients admitted to the ICU who developed severe AKI. This study found higher diuretic usage among patients with a higher VExUS score. Similarly, Bhardwaj *et al*[52] demonstrated a significant correlation between AKI injury resolution and improvement in the VEXUS grade, as well as a significant association between changes in the VEXUS grade and fluid balance. Both AKIVEX[51] and Bhardwaj *et al*[52] highlighted that traditional parameters such as central venous pressure, fluid balance, peripheral oedema, and weight gain were not



In this pulse-wave (PW) doppler study, the renal artery doppler waveform appears above the baseline, and the renal vein doppler waveform appears below it. This picture is an example of a normal renal vein doppler waveform, which is monophasic throughout the cardiac cycle, with the orange arrow indicating systole and the yellow arrow indicating diastole

In this pulse-wave (PW) doppler study, the renal artery doppler waveform appears above the baseline, and the renal vein doppler waveform appears below it. This picture is an example of an abnormal renal vein doppler waveform in which there is a discontinuous biphasic flow with distinct systole and diastole phases, with the orange arrow indicating systole and the yellow arrow indicating diastole

Figure 9 Examples of the renal vein Doppler waveform. Renal interlobar or arcuate veins are the optimal Doppler sampling sites while performing Venous Excess Ultrasound grading assessments for renal veins. A: Normal renal vein doppler waveform which is monophasic throughout the cardiac cycle; B: Congested renal vein will exhibit a discontinuous biphasic flow with distinct systole and diastole phases; C: Renal interlobar vein.

different between the group with ultrasonographic evidence of venous congestion and the group without congestion.

GENERAL MONITORING AND PROGNOSIS

The prospective multicentric study by Andrei *et al*[53], which looked at 145 patients in the general ICU, found that the prevalence of systemic venous congestion assessed by the VExUS is low. Besides, VExUS scores did not significantly change during the first days of the ICU stay, and systemic venous congestion (VExUS ≥ 2) was not associated with AKI or 28-day mortality. This study distinguishes itself from earlier studies that focused on cardiac or nephrology patients by examining a more diverse cohort of non-cardiac patients, including those with septic shock, trauma, and stroke, who typically do not showcase significant cardiac disease or hypervolemia. The findings suggest that various non-cardiac factors contribute to AKI risk in the general ICU population, indicating that moderate congestion alone may not be the primary factor driving AKI. Furthermore, these findings were consistent with the AKIVEX[51] study, which was conducted among ICU patients with severe AKI and found that there is a higher prevalence of sepsis among those with VExUS ≤ 1, indicating that the AKI in this group is likely due to sepsis rather than congestive nephropathy.

Apart from studies performed in the cardiac, nephrology and intensive care unit settings, Landi *et al*[54] did a study in the emergency setting among patients with acute decompensated heart failure. Landi *et al*[54] found severe venous congestion, defined as a VExUS score of 3 at the initial assessment predicted inpatient mortality, heart failure-related death, and early readmission. This study highlighted that the VExUS score was found to be technically feasible in almost all patients, despite tachypnoea and incomplete cooperation, proving feasibility and adequate interpretation even in an emergency department setting.

LIMITATIONS OF VEXUS

The VExUS grading system, while valuable in assessing venous congestion, has its own limitations, especially in the image acquisition and interpretation challenges. The VExUS grading system involves different structures, each susceptible to certain caveats. Several factors can affect the size of the IVC, making its interpretation challenging at times. These include respiratory effort, positive ventilation, cardiac pathology such as right heart failure or tricuspid regurgitation, intra-abdominal pressure, and not to forget about local mechanical factors such as the presence of an IVC filter, IVC thrombosis, or the presence of an ECMO catheter. Tricuspid regurgitation, pulmonary hypertension, and right heart failure may all lead to persistent IVC dilation. Therefore, these conditions may consistently elevate the VExUS score, making normalization unattainable. Additionally, the use of high positive end expiratory pressure and low tidal volume ventilation during the treatment of acute respiratory distress syndrome may also lead to a larger IVC. In any healthy individual, portal vein pulsatile flow is observable during deep inspiration. Furthermore, because the pulsatility of portal veins inversely correlates with body mass, individuals with low body weight can also observe portal vein pulsatile flow despite absence of venous congestion. Individuals with stiff liver parenchyma, such as those suffering from cirrhosis or

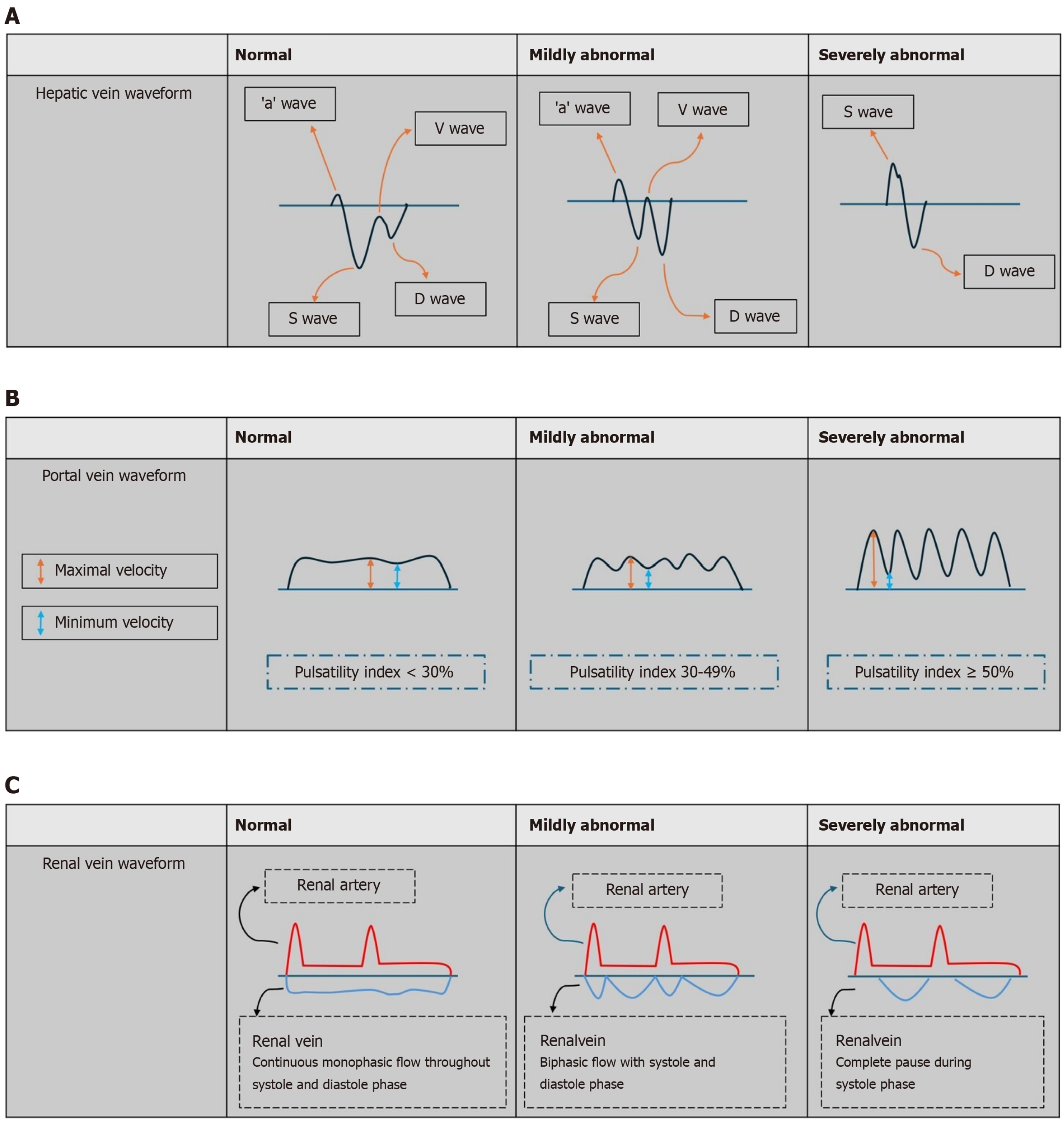

A
Normal
Mildly abnormal
Severely abnormal
Hepatic vein waveform
'a' wave
V wave
S wave
D wave
'a' wave
V wave
S wave
D wave
S wave
D wave
B
Normal
Mildly abnormal
Severely abnormal
Portal vein waveform
Maximal velocity
Minimum velocity
Pulsatility index < 30%
Pulsatility index 30-49%
Pulsatility index ≥ 50%
C
Normal
Mildly abnormal
Severely abnormal
Renal vein waveform
Renal artery
Renal vein
Continuous monophasic flow throughout systole and diastole phase
Renal artery
Renalvein
Biphasic flow with systole and diastole phase
Renal artery
Renalvein
Complete pause during systole phase

Figure 10 Graphic representation of the interpretation of the venous excess ultrasound grading system. Grade 0: Inferior vena cava (IVC) < 2 cm signifying no congestion. A: Grade 1: IVC ≥ 2 cm and any combination of normal or mildly abnormal waveforms, reflects only mild congestion; B: Grade 2: IVC ≥ 2 cm with one severely abnormal waveform, indicating severe congestion in a single organ; C: Grade 3: IVC ≥ 2 cm with ≥ two severely abnormal waveforms, denotes severe congestion affecting at least two organ system.

non-alcoholic fatty liver disease, may exhibit altered hepatic vein waveforms characterized by diminished phasic oscillations, as well as a non-pulsatile portal vein, which can occur even in the presence of significant venous congestion. These changes are indicative of increased resistance to blood flow due to fibrosis or steatosis in the liver[17,32]. As mentioned earlier, renal vein image acquisition can be challenging, and interpretation of the hepatic vein waveform without ECG tracing guidance can be misleading.

CONCLUSION

In summary, VExUS serves as a valuable tool for identifying venous congestion. It should be integrated with traditional diagnostic assessments, which include a comprehensive clinical history, physical examination that includes lungs auscultation, pedal oedema, skin turgor, jugular venous pressure, and the interpretation of cardiothoracic ratio in chest X-rays. This integration can enhance the accuracy of the overall diagnostic assessment. The VExUS score can also serve as a monitoring parameter after therapeutic measurements. Despite involving multiple assessment components, such as the use of a color Doppler and spectral Doppler, the overall performance is feasible and manageable with a thorough understanding of the technical aspects and proper guidance from individuals who are familiar and experienced with VExUS usage.

FOOTNOTES

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